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MICROGRAVITY PLANT NUTRIENT EXPERIMENT WATER AVAILABILITY SENSOR

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Abstract

A Kennedy Space Center team is developing the Microgravity Plant Nutrient Experiment (MPNE) middeck payload to support plant growth in microgravity for the United States Space Program. The fluid system in this payload employs porous plant tubes that deliver nutrient solution actively to the plant roots and replaces the need for soil to grow plants. The key component controlling nutrient solution delivery to the plant tubes is the Water Availability Sensor (WAS). This paper describes the method used by this sensor to measure the thin film of plant nutrient solution or potable water on plant tubes in the MPNE payload and to provide the feedback logic for nutrient delivery to plants. The WAS provides an noninvasive measurement of nutrient delivery for this unique hydroponic system and nutrient solution is added to the fluid system network as it is consumed by the plants. The team's long term goal is to produce a highly controllable nutrient delivery system that will be a prime candidate for long term plant growth on the Space Station.

Fluid Network Hardware

The heart of the MPNE payload is a network of fluid handling hardware (see Figure 1). The network manages and manipulates fluid to grow plants in a microgravity environment. Potable water was used for initial tests and a plant nutrient solution will be used for the Shuttle mission. This solution is composed of 0.06 grams of salts per 100 milliliters of water and is modeled as water for measurements. The design and function of the flight hardware are described in the following sections.

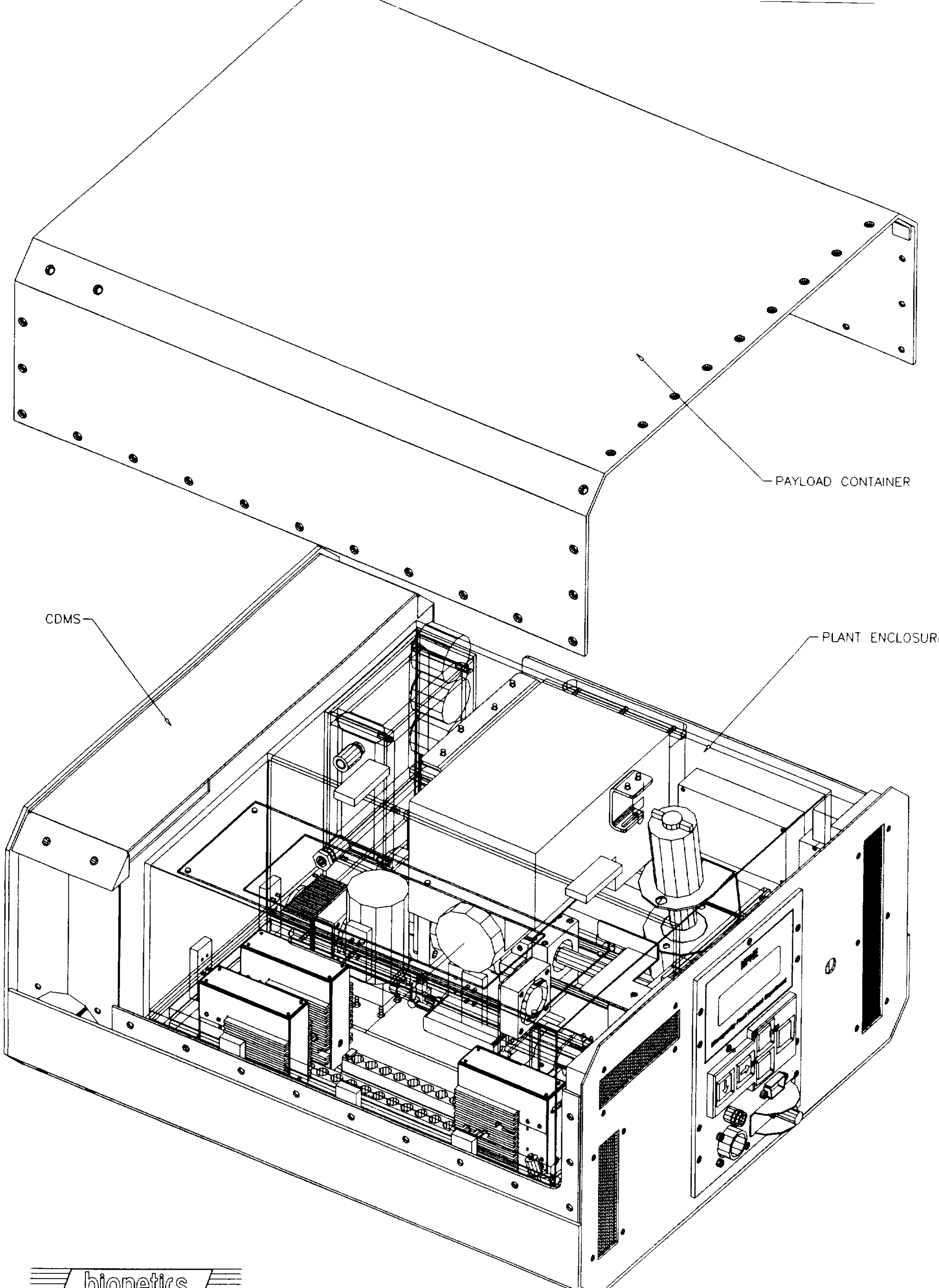

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FIGURE 1 - MICROGRAVITY PLANT NUTRIENT EXPERIMENT PAYLOAD

Sensor Description

The prototype Water Availability Sensor (WAS) developed in 1992 uses infrared absorption to detect the quantity of plant nutrient solution or water on the surface of the MPNE plant tubes. The WAS measures fluid on an area of the plant tubes without physically touching any part of the tube. This sensor detects incident radiation at a very strong infrared absorption band for water centered at 2800 nanometers (nm) in the infrared (IR) spectrum. An incandescent lamp generates the necessary IR radiation which is directed onto the plant tube. Most of the infrared radiation is reflected by a dry plant tubes and absorbed by a wet tube.

A portion of the reflected radiation is detected by a PbS (Lead Sulfide) detector, while a second PbS detector is used to monitor the lamp intensity and act as reference for temperature changes. The detector is a variable resistance device that outputs a resistance dependent on the amount of incident radiation. The two detector signals are processed electronically to convert the detector's resistance change into a corresponding voltage change. A computer program uses the voltage produced as feedback to control the Water Delivery System (WDS) that supplies water or plant nutrient solution to the plant tube.

A second generation WAS has been developed that builds on the success of the first device and improves on weaknesses. The same basic design principles are used for the flight sensor as in the prototype with emphases on correcting the prototype design short-comings. The new design uses a single infrared (IR) detector with an integral thermal electric cooler (TEC). The TEC keeps the detector at a constant operating temperature eliminating the need for a second reference detector.

The current WAS IR source is a 0.1 mW Diode-LASER (DL) operating at 1550 nm. The 2800 nm region used in the first generation device is a very good water absorption peak but the IR component technology is rather limited in that region. Calculations and preliminary testing show that the IR absorption of water at 1550 nm although weaker than that at 2800 nm is well suited to this application. The signal to noise ratio of an improved IR detector surpasses the prototype by having an integral amplifier in the detector. The overall gain is increased compensating for the weaker IR absorption at the shorter operating wavelength. This increased gain in combination with the matched optics proves to be very effective in measuring a wide range of fluid thickness expected on the plant tubes. Also, the DL chosen is modulated at a higher frequency (1 kHz) than the incandescent lamp used in the prototype providing an superior system response time.

A surface-mount technology printed-circuit board (PCB) is located within the sensor package that reduces other noise effects. The PCB contains the circuitry for control of the DL and sampling of the IR detector output. The DL is modulated by an 1 kHz square wave. The transistor-transistor logic (TTL) modulation signal is amplified and sent to the DL. The DL package contains an integral photodiode for detection of the output power being produced by the DL itself. This photodiode signal is returned to the amplifier to assist in keeping the DL power output constant with temperature. A sample and hold (S/H) amplifier is also located on the PCB. The S/H amplifier is synchronized with the modulation of the DL to provide for a 1 microsecond sample of the IR detector output every 1 millisecond.

The WAS packaging is designed to limit unwanted component movements and eliminate heat generated by the DL and TEC. Figure 2 illustrates the DL source and IR detector attachment to a single mounting block. The first surface and an ellipsoidal mirror that direct the IR beam onto the plant tube are attached to kinematic mounts to provide for precise optical alignment. These and other packaging techniques improve the WAS repeatability as compared to the prototype design.

The WAS calibration method is also improved from the prototype concept and is based on changes in the fluid volume on the tube surface. This new plan for correlating the WAS output voltage to a corresponding fluid thickness assumes the fluid is evenly distributed along the tube surface both axially and radially. This model is reinforced by the noninvasive WAS that does not alter the actual fluid distribution as it measures.

A single plant tube with containment septums plugging each end and a WAS attached is mounted in a precision balance for wetness observations and fluid thickness-to-weight measurements. These measurements are correlated directly to WAS voltage readings for film thickness definition. Boundary conditions defining visibly dry and visibly wet are established by human observation as a first step in this calibration method.

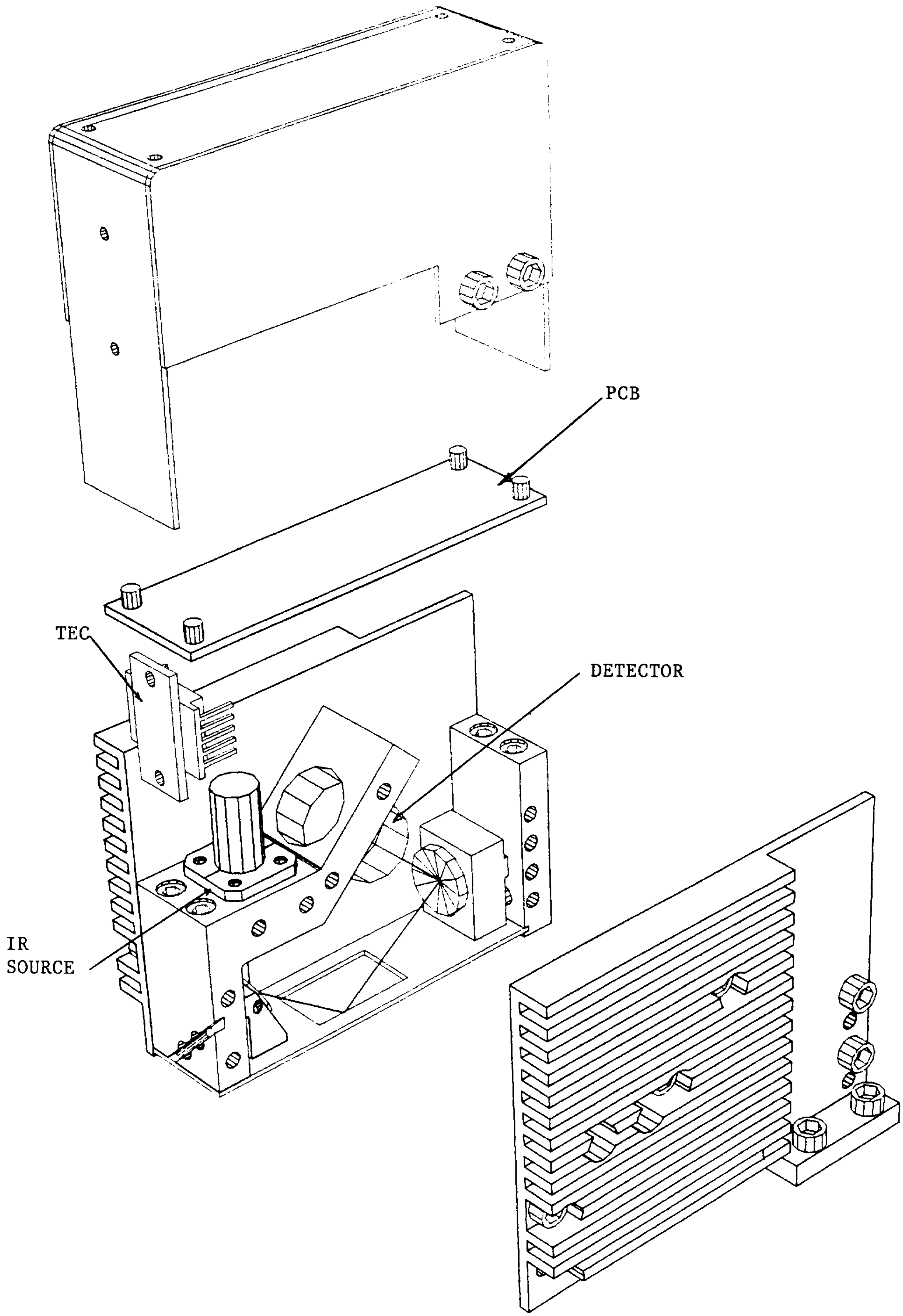

FIGURE 2 - WATER AVAILABILITY SENSOR (WAS)

Generally, the WAS can detect fluid levels most precisely starting at the point where the tube becomes discolored from the water or "visibly dry". Water is then injected into the tube through the containment septums until droplets form and begin to fall from the underside of the tube. This second condition is defined as "visibly wet".

Water in the loaded plant tube is allowed to evaporate passively. As this occurs, the weight obviously decreases as the WAS reading increases because less light energy is absorbed. The tube transitions from the wet condition to the dry condition over a period of approximately one day. These data create a WAS versus water thickness profile. Measurements of a typical plant tube being used for plant growth show a 1 to 10 micron water film on the surface of the tube. The total fluid mass for the Shuttle experiment is measured before flight and after landing. The mass balance and plant weights are important data in determining plant performance.

Water Delivery System

The MPNE mission will test the ability of the hardware to deliver nutrient solution to the plant specimens located on the plant tubes. This delivery is accomplished by the Water Delivery System (WDS) which includes integrated hardware and software components. A functional diagram of the WDS, WAS and MPNE fluid loop is shown in Figure 3.

The purpose of the WDS is to control the amount of fluid located on the plant tube surface as a thin film. This task is accomplished with a closed loop configuration. A WAS located over each plant tube senses the fluid thickness on the surface of the tube.

The WAS voltage output is received by the computer through an A/D converter, where it is digitized and made available to the software. The input is compared to a set point stored in memory and defines the corrective action to be taken to adjust the fluid thickness. This set point is changed in real-time by the user or by the experiment profile data file.

A Fuzzy Logic control algorithm is the command methodology employed for corrections. This controller is implemented using software written in ANSI C. The fuzzy controller uses the present state error, past error, proportional gain, differential gain, and integral gain to calculate any corrections to the fluid loop required. The output of the fuzzy algorithm indicates the direction and the number of steps for the WDS stepper. This direction and step number is then converted by the software into a sequence of 4-bit values that are written to the stepper motor using digital outputs to perform the actual motor movement. This motor movement is mechanically translated to a linear displacement of a syringe piston by the WDS lead screw. The WDS either adds to or subtracts fluid from the network and in turn the plant tube. The new wetness amount caused by this change in water is then detected by the WAS, and the process continues in a closed-loop fashion.

The system also contains a fuzzy logic autotuner. The autotuner adjusts the values for the proportional, differential, and integral gains in real-time by bumping the system at periodic intervals and tuning the system characteristics appropriately. The tuner looks at trends in overshoot, undershoot, rise time, and frequency of the overshoot and undershoot to determine these changes.

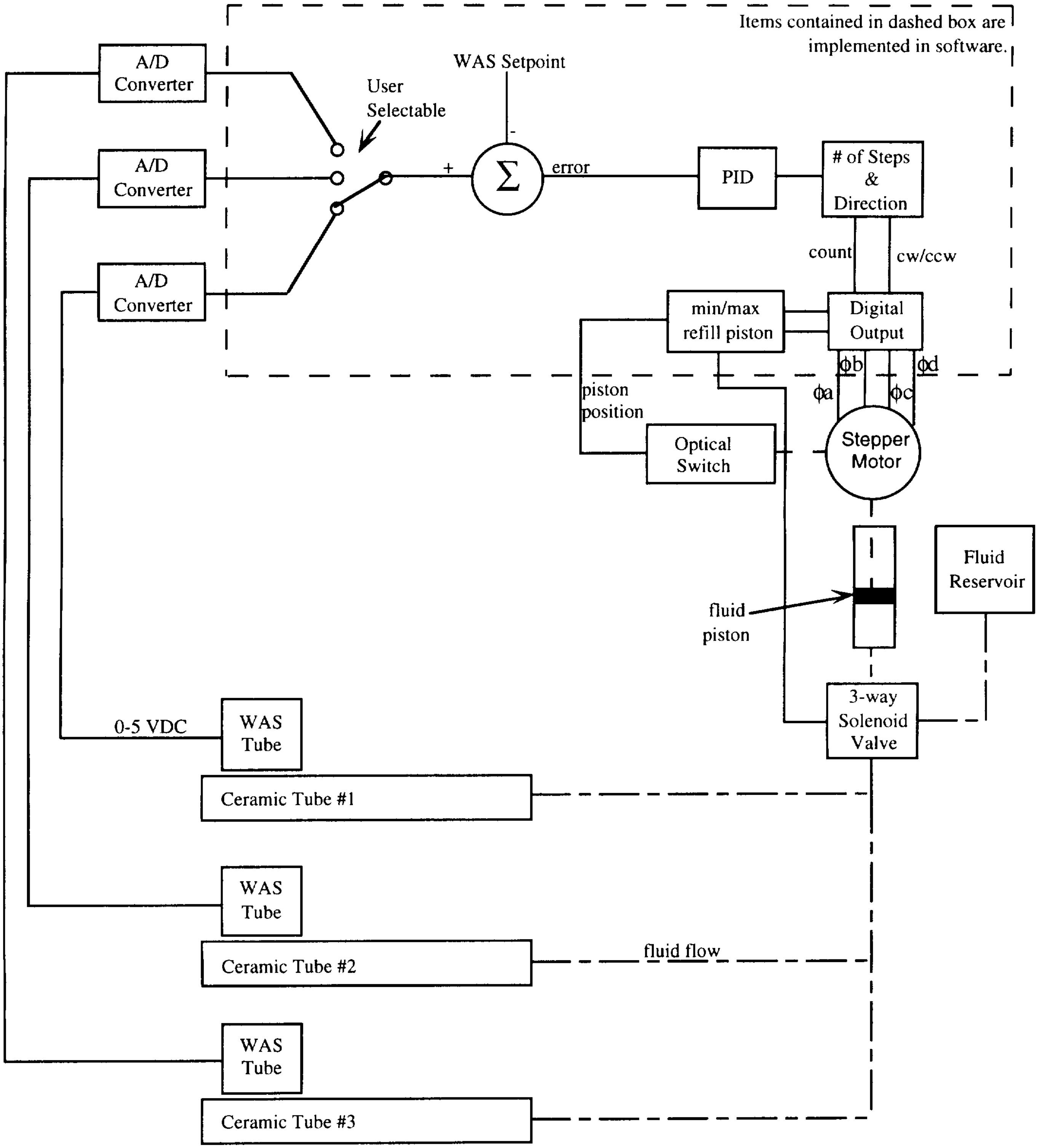

Figure 3 - MPNE functional diagram

The software also monitors the position of the syringe piston during control of the nutrient delivery. A syringe refill cycle is initiated when the piston is fully extended and the syringe is empty. This refill cycle is accomplished by energizing the 3 way solenoid valve and retracting the syringe piston to its full back position to draw fluid from the reservoir. Once the syringe piston is full back and the syringe is full the solenoid valve is de-energized returning the syringe connection to the main fluid network. Normal nutrient delivery is resumed.

Conclusions

The WAS provides a simple, noninvasive fluid thickness measurement as part of a fluid control loop in microgravity. The sensor's operating characteristics, accuracy, and compactness are well suited for the Space Shuttle and Space Station environment. The integration of hardware and software multiply the sensor's capacity for data collection and nutrient delivery control.

Infrared technology applied for this unique plant growth system could be adapted to measure thin films in other systems.

Acknowledgments

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